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ELECTRONICS RESEARCH LABORATORY

Electronic Warfare Division

RESEARCH NOTE
ERL-0630-RN

THE TIME DOMAIN RESPONSE OF BICONICAL HORNS

by

Kenneth M. Harvey

23/2

SUMMARY

Time domain reflectometry derived from 40 GHz vector network analyser data is used to analyse a pair of biconical horn antennas. Such a technique provides insight into the operation of these antennas and is useful to the designer who wishes to optimise performance.

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1 INTRODUCTION

Biconical horn antennas (bicones) are used extensively to provide omnidirectional coverage for a variety of radio frequency systems. In almost all cases the antenna is fed by means of a coaxial line through the axis of one half with the centre conductor connecting with the other half.

The impedance match of such an antenna is subject to a number of factors as follows:

(a) Non-perfect connector.

(b) Discontinuity effects at the feed point, being a function of the spacing between the 2 halves of the antenna.

(c) Impedance mismatch of the tapered section.

(d) Diffraction effects at the aperture.

(e) Reflections of the radome.

This paper examines the first four effects by means of the time domain reflectometry feature of a 40 GHz Wiltron 360 network analyser which can separate out these sources of reflection to a high resolution and so give the designer a better insight into the operation of the antenna.

2 TEST BICONES

Two small bicones were constructed, the diameter of each being 65.8 mm, with an included angle of 46.4 degrees within the aperture. This angle was chosen to give an impedance of 50 ohms in the tapered section (see Reference 1). Bicone 1 (see Figure 1) had a conventional aperture that incurred a high level of diffracted waves whilst bicone 2 (see Figure 2) was rounded at the aperture to a nominal radius of 20 mm in order to reduce these diffraction effects. SMA connectors, having a mode free response up to at least 25 GHz, were fitted to each bicone.

3 MEASUREMENTS

The Wiltron 360 network analyser has a time domain feature that enables either the impulse or step responses to be displayed. The former response was found to be most useful for this study. An extension of this allows for the impulse response of a particular discontinuity to be selected to the exclusion of all others and for the return loss, say, of that discontinuity to be displayed also.

Figures 3 and 4 show the impulse response of bicones 1 and 2 respectively. The connector in each case extends from 0 to 50 ps in the time domain whilst the feed point extends from 50 to 100 ps. The tapered section of each horn extends from 100 to 150 ps and since this section is designed to be 50 ohms, very little return from this is seen. This is more clearly demonstrated by observing the step response (not shown here) although the impedance of this section may not be constant for all bicone spacings. The aperture effects are noted after 150 ps delay. It can be seen that the curved aperture edge does indeed reduce the level of diffracted wave by a small but noticable amount.

By the process of gating the Wiltron 360 in its time domain mode of operation, referred to earlier, the return loss of each section can be displayed. The impulse response was broken up into sections using the time breaks listed above. The return loss of the tapered section was not so measured as it was deemed non-contributory. The return losses for the connector, feed point and aperture for bicone 1 are shown in Figures 5, 6 and 7 respectively together with the return loss for the bicone as a whole. The aperture results for bicone 2 are shown in Figure 8.

Quite clearly bicone 2 has an improved low frequency response to bicone 1 that could be improved even further by rounding the aperture edges with a larger radius of curvature.

4 FEED POINT EQUIVALENT CIRCUIT

For the above tests the 2 cones forming the antenna are arranged so that the virtual apices of each coincide. The impulse response of the feed section in this case is seen to be typical for a series inductive element. This response is shown more clearly in Figure 9 in which all other responses have been gated out. If the cones are arranged closer together, then the responses are as indicated in Figures 10 and 11 with the latter being for the cones almost abutting. This last response is that of a shunt capacitance. Consideration of these results and the geometry suggests that the equivalent circuit for this feed point is a PI network as shown in Figure 12.

The geometry of the feed point is similar to that of a radial-line/coaxial-line junction for which the equivalent circuit has been derived (see References 2, 3 and 4). Figure 13 shows the equations for the element values (Reference 4) and Appendix I lists the computer program which calculates the input impedance and return loss of such a circuit terminated in 50 ohms. This program considers only the first radial mode but comparison with the results from the program listed in Reference 3 shows this assumption to be well based.

Figure 14 shows the measured input impedance (dashed lines) of the feed section obtained after gating, together with the calculated values (solid lines) for three different spacings. The frequencies range from 0.08 to 40 GHz with the marker at 15 GHz. Whilst there are discrepancies due to the approximation in geometry, the general forms of the impedance curves correspond well.

5 CONCLUSION

This note demonstrates the use of time domain reflectometry as a diagnostic tool in the understanding and design of bicone antennas. This technique could be extended when the antenna is fitted with a radome.

ACKNOWLEDGEMENTS

Thanks are due to Dr Bevan Bates for useful discussions and for supplying the equivalent circuit of the coaxial-line to radial waveguide junction.

REFERENCES

1. "Antenna Engineering Handbook" H. Jasik, p 10-14.

2. "Equivalent circuit for radial-line/coaxial line junction" A.G. Williamson, Electronics Letters,16 April 1981, p 300.

3. "Radial-line/coaxial-line junctions" A.G. Williamson, U. of Auckland, School of Engineering Report No. 332, 1984.

4. Bevan D. Bates, private communication.

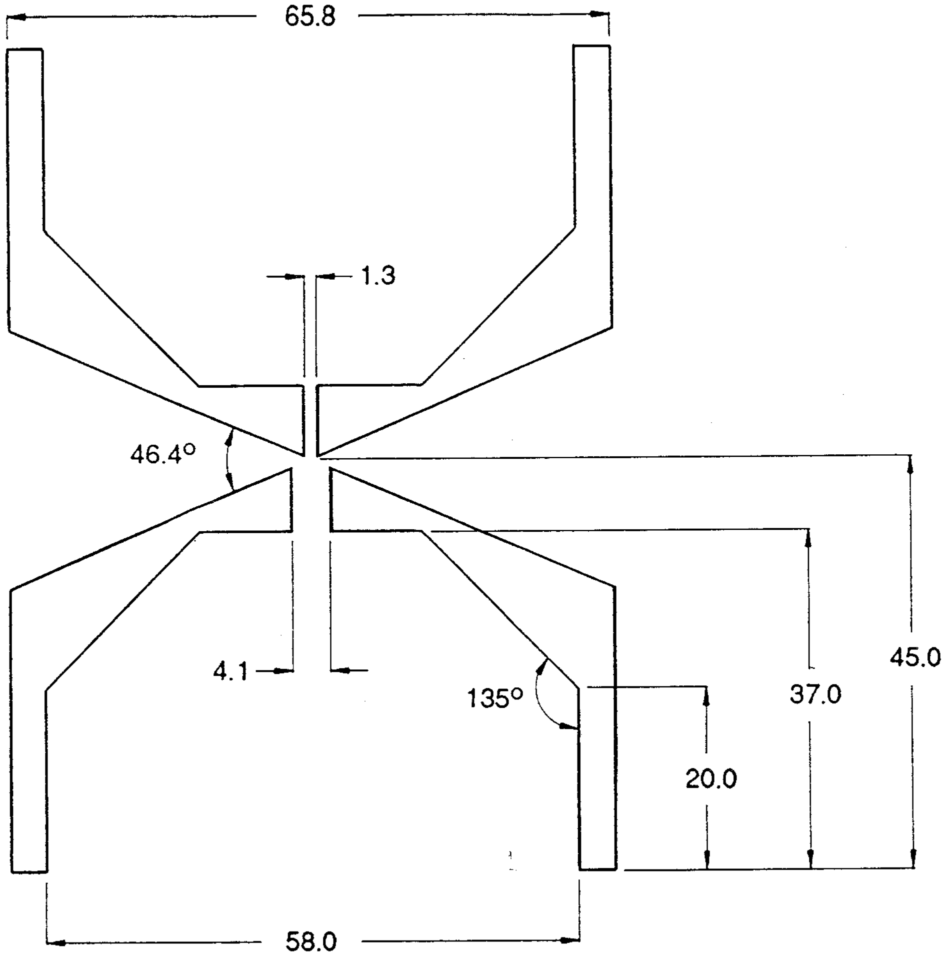


Figure 1 Bicone 1.

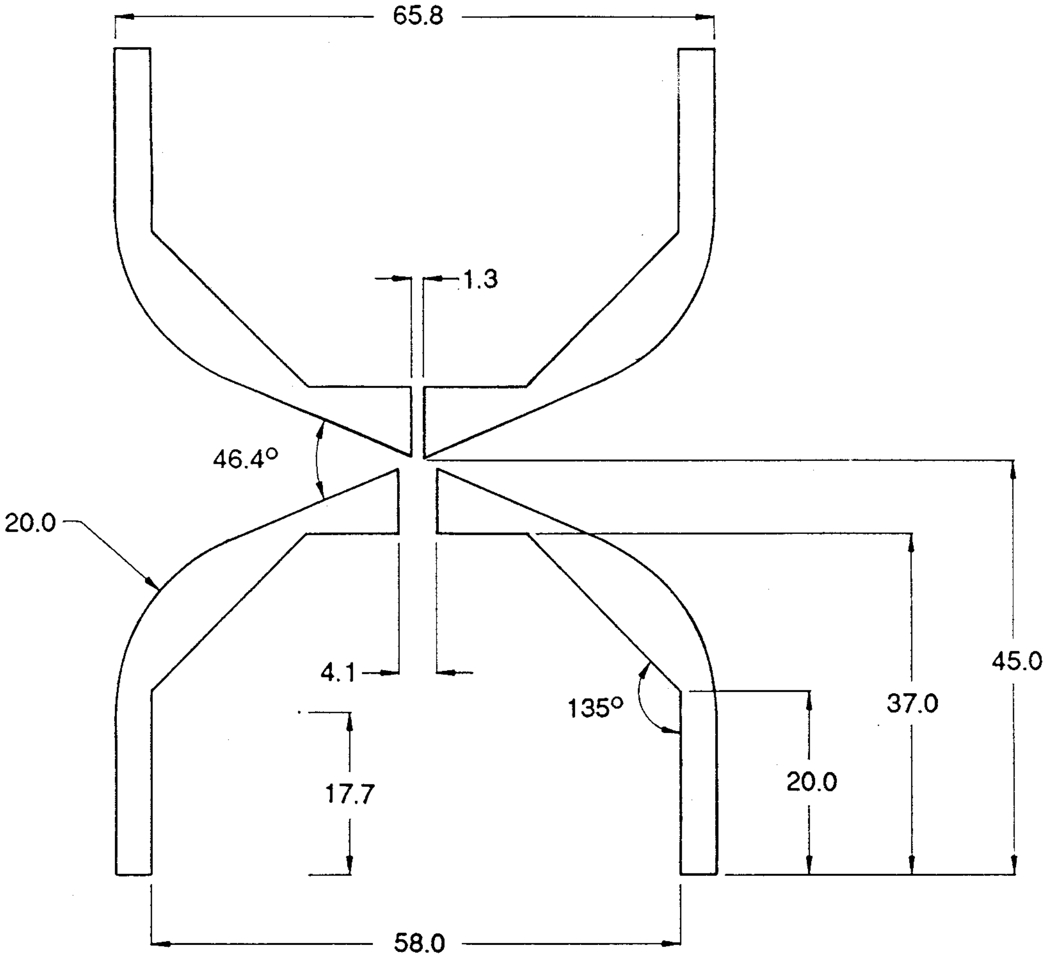


Figure 2 Bicone 2.

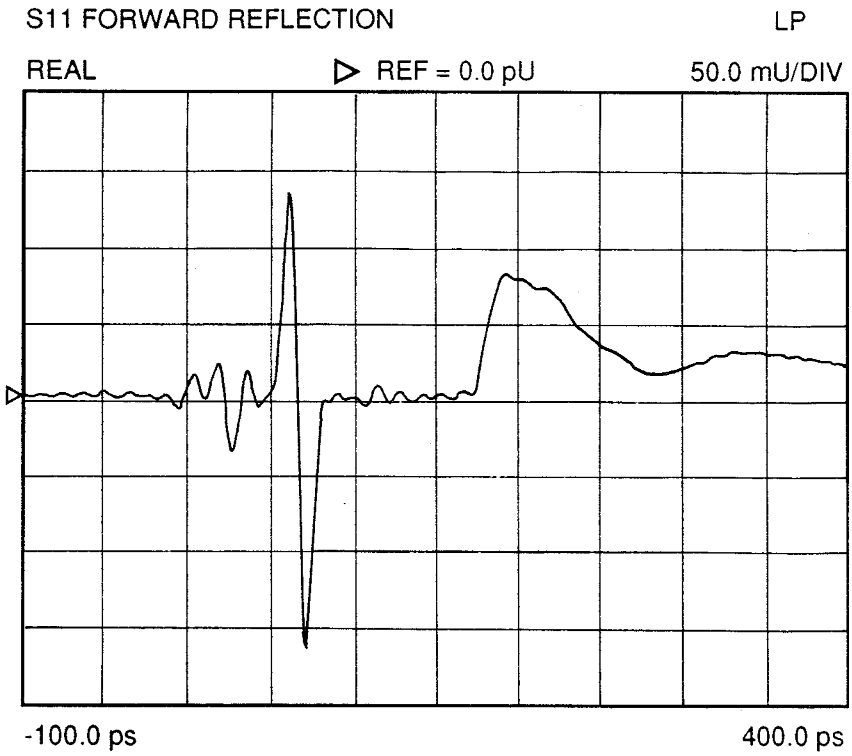


Figure 3 Impulse response of Bicone 1.

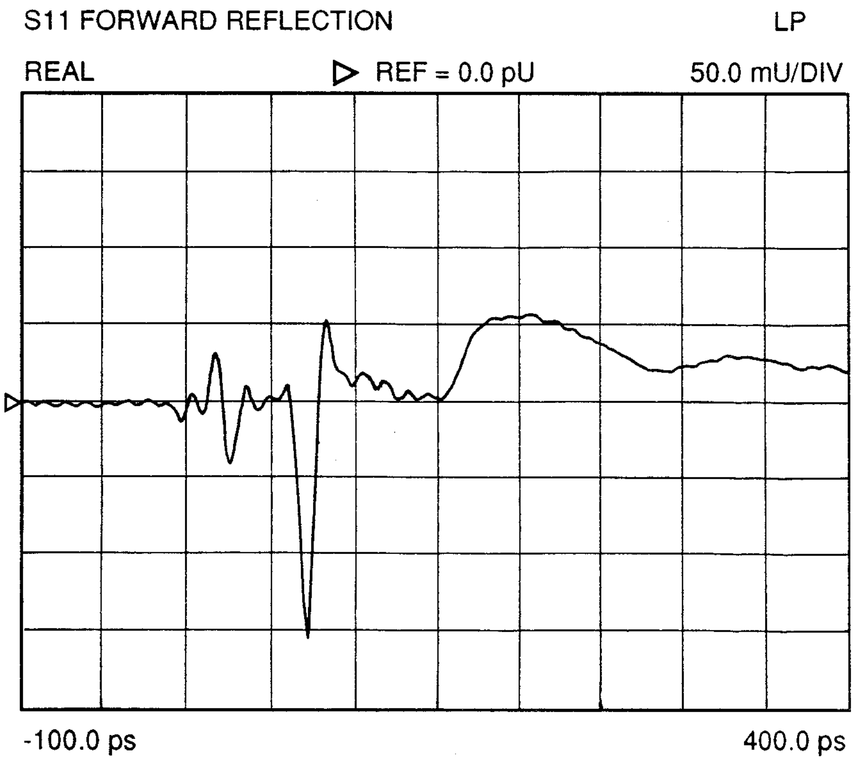


Figure 4 Impulse response of Bicone 2.

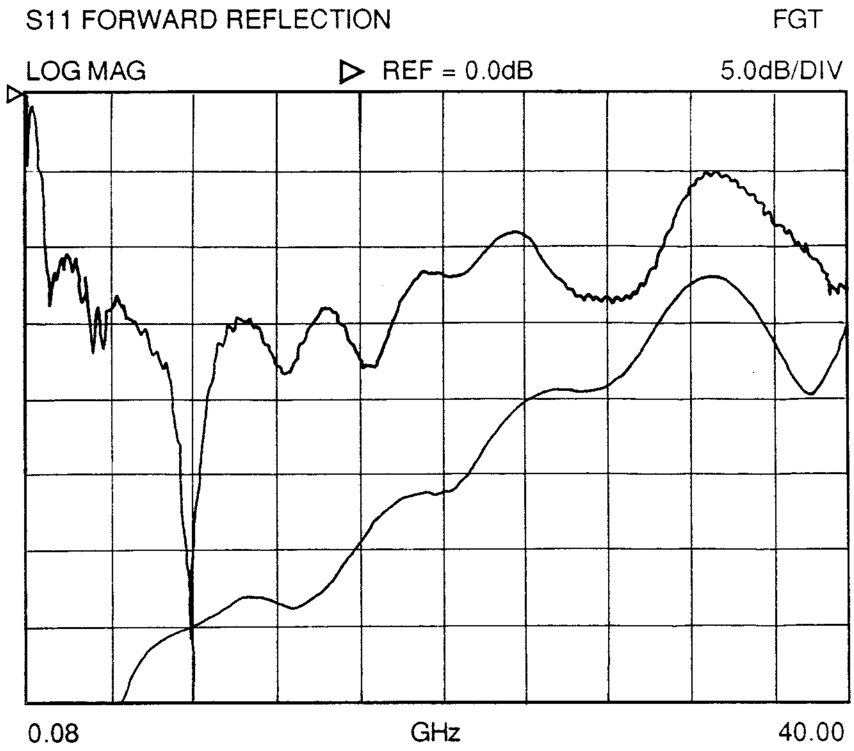


Figure 5 Return loss of Bicone 1 (upper) and return loss of connector (lower).

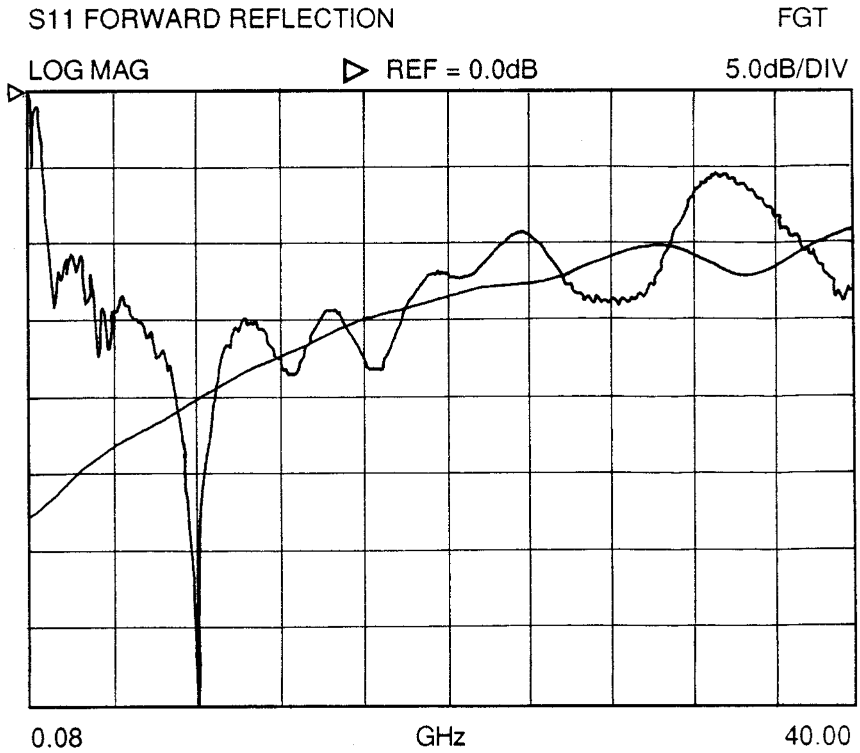


Figure 6 Return loss of Bicone 1 (upper) and return loss of feed point (lower).

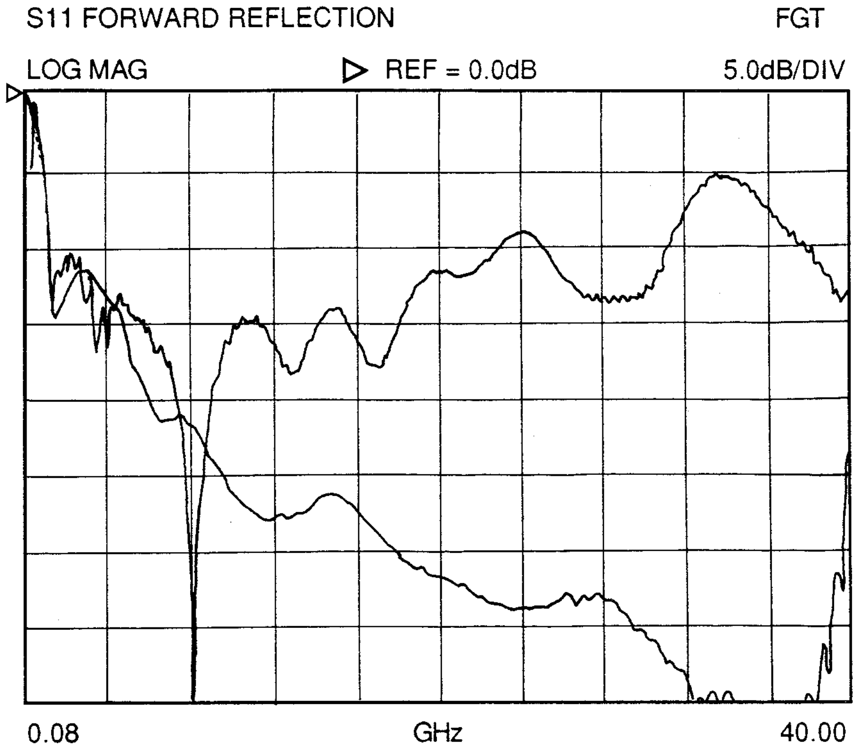


Figure 7 Return loss of Bicone 1 (upper) and return loss of aperture (lower).

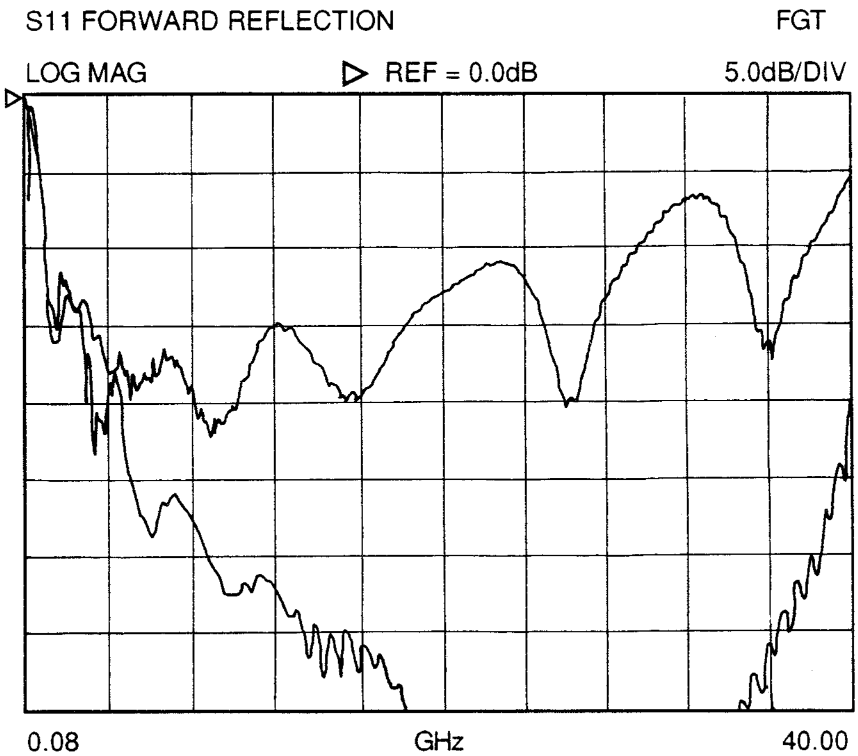


Figure 8 Return loss of Bicone 2 (upper) and return loss of aperture (lower).

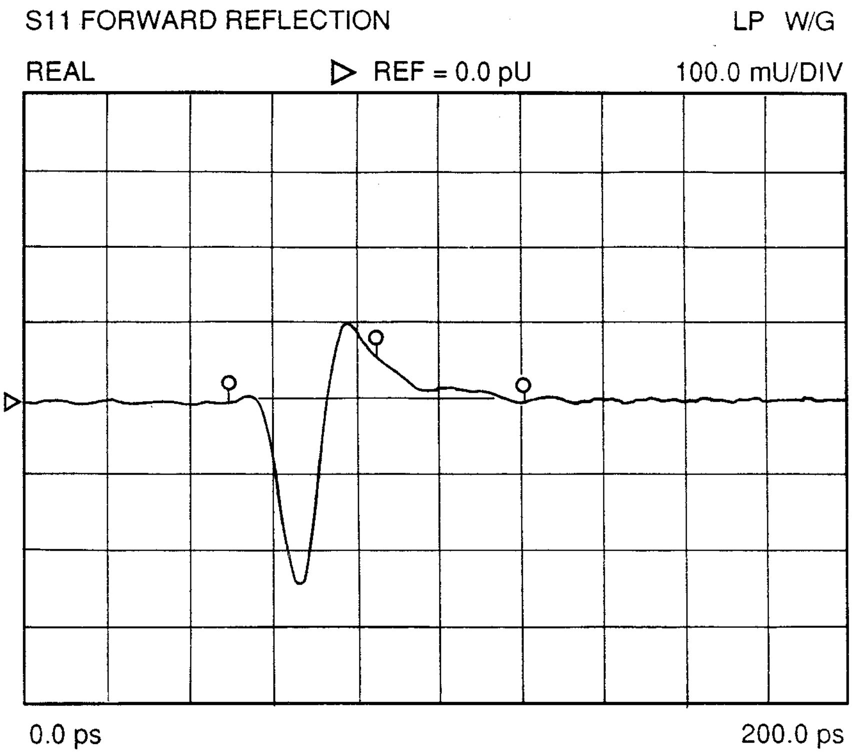


Figure 9 Impulse response of Bicone 1 feed point (wide separation).

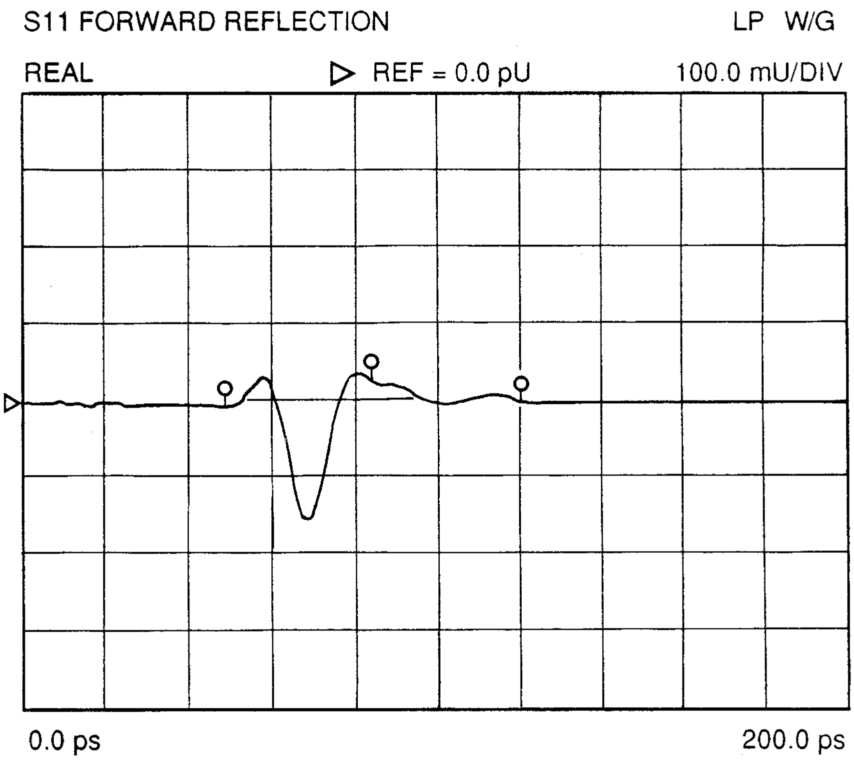


Figure 10 Impulse response of Bicone 1 feed point (medium separation).

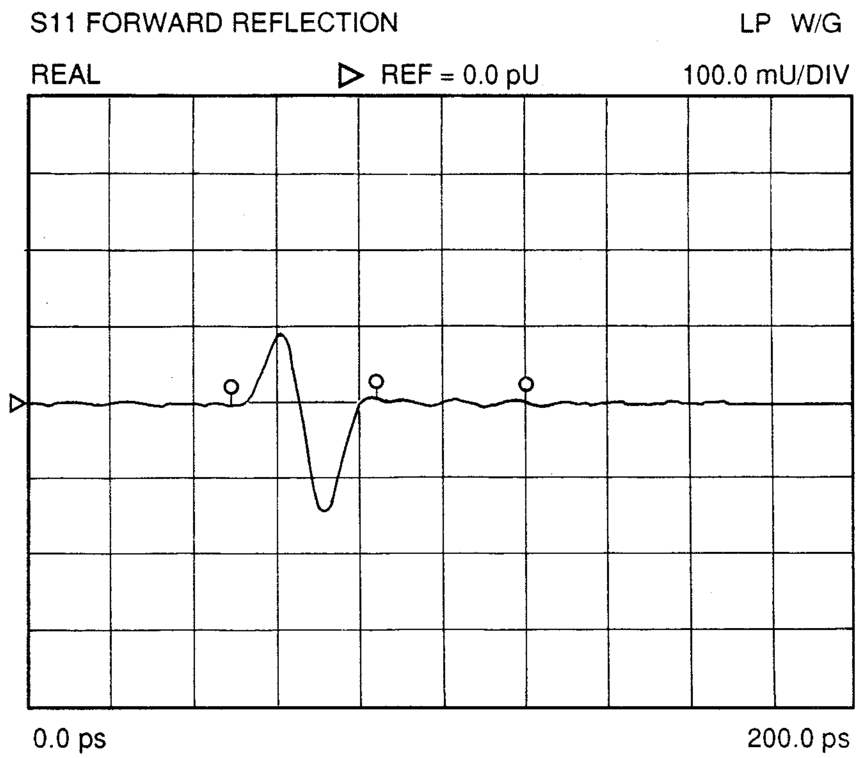


Figure 11 Impulse response of Bicone 1 feed point (close separation).

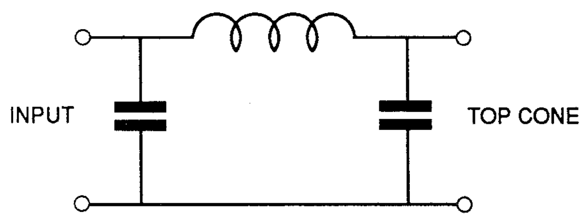
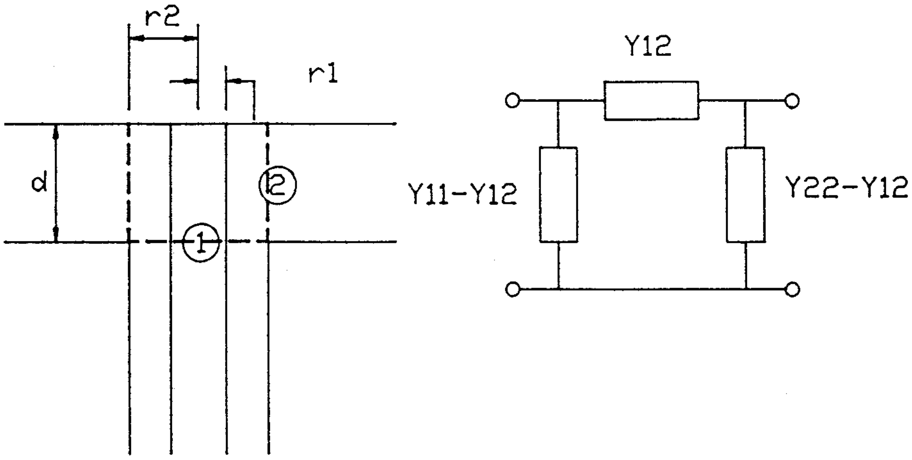


Figure 12 Suggested equivalent circuit of bicone horn feed point.



$$Y11 = -j \cot(kd)/Z$$

$$Y12 = -j/(kZd)$$

$$Y22 = -j \frac{2\pi r2}{dZ_{fs}} \left[\frac{Jo(kr1)Y_1(kr2) - Yo(kr1)J_1(kr2)}{Jo(kr2)Yo(kr1) - Yo(kr2)Jo(kr1)} \right]$$

where

$$Z = \frac{1}{2\pi} \sqrt{\frac{\mu}{\varepsilon}} \ln \left[\frac{r2}{r1} \right]$$

$$k = 2\pi f/c$$

$$c = \frac{1}{\sqrt{\mu \varepsilon}}$$

$$Z_{fs} = \sqrt{\frac{\mu}{\varepsilon}}$$

Figure 13 **Equivalent circuit of a coaxial line to radial waveguide junction.**

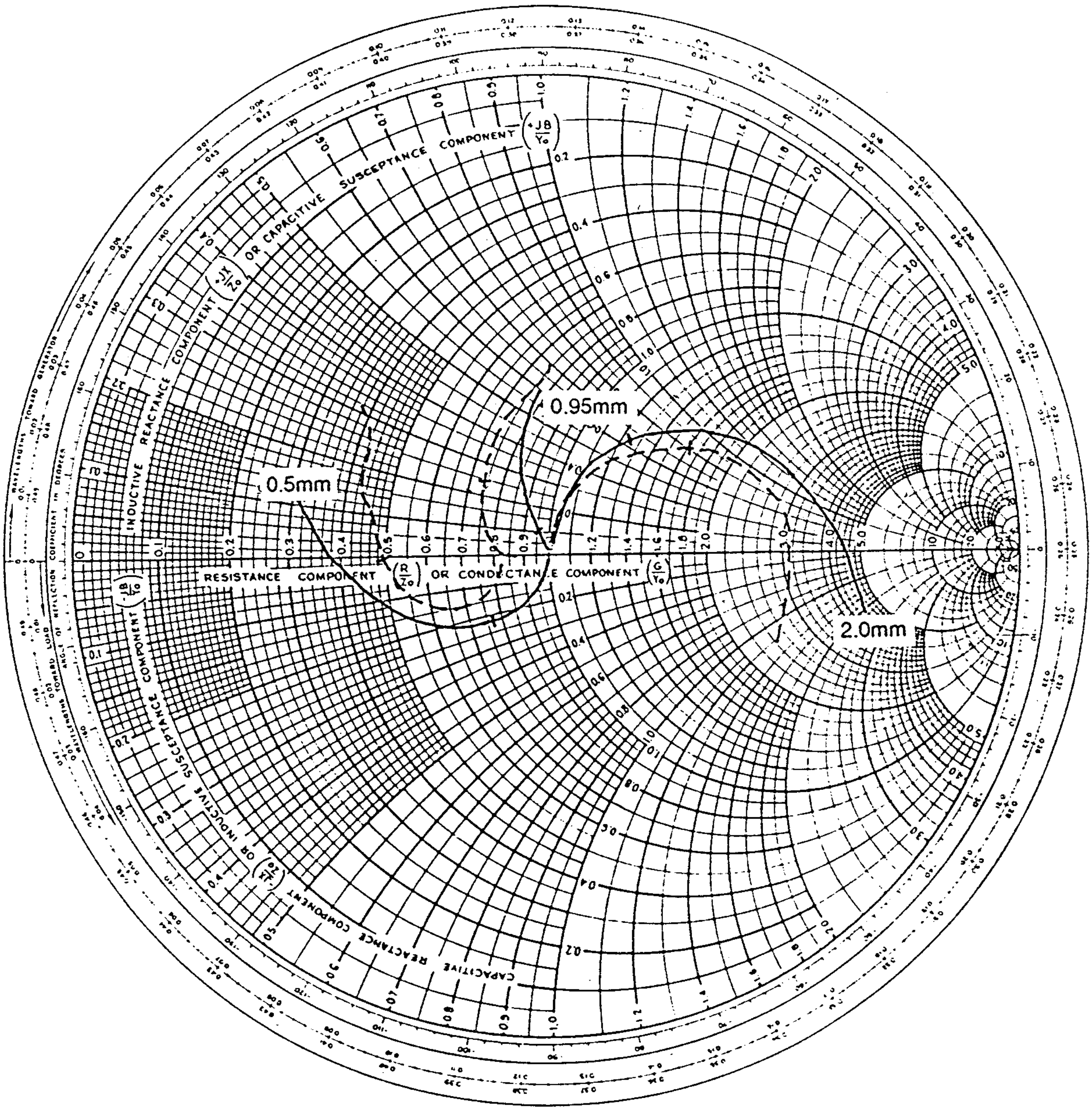


Figure 14 Input impedance of Bicone 1 feed point (--- measures,___ calculated).

APPENDIX I PROGRAM LISTING

```
C PROGRAM BICONE.FOR
C COMPUTES THE IMPEDANCE OF A COAX-TO-RADIAL WAVEGUIDE TRANSFORMER
C AS AN APPROXIMATION TO THE FEED OF A BICONICAL HORN ANTENNA.
C OUTPUTS THE RETURN LOSS.
C ASSUMES THAT THE EQUIVALENT CIRCUIT IS A PI NETWORK
      REAL*4 J01,J02,J11,J12,K
      COMPLEX*16 YY11,YY21,YY22,Y1,Z2,Y3,A,B,C,D,S11,ZIN
      CHARACTER*1 ANS
  PI=3.141592654
      C0=2.998E8
      E0=8.8541853E-12
      U0=1./(E0*C0*C0)
C ***********************************
C READ INPUT PARAMETERS
1000  WRITE(6,1)
1     FORMAT(' INPUT WAVEGUIDE SPACING (MM) ')
      READ(5,*)D1
      D1=D1/1000.
      WRITE(6,2)
2     FORMAT(' INPUT COAX INNER AND OUTER DIAMETERS (MM) ')
      READ(5,*)R1,R2
      R1=R1/2000.
      R2=R2/2000.
      WRITE(6,3)
3     FORMAT(' INPUT START, FINISH AND INCREMENTAL FREQUENCY (GHZ) ')
      READ(5,*)FL,FU,FINC
      FL=FL*1.E9
      FU=FU*1.E9
      FINC=FINC*1.E9
      F=FL
      WRITE(6,7)
7     FORMAT('         F        R/LOSS(DB)')
C FG IS THE CURRENT FREQUENCY IN GHZ USED FOR THE OUTPUT STATEMENT
10    FG=F/1.E9
      ZC=1./2./PI*SQRT(U0/E0)*LOG(R2/R1)
      K=2.*PI*F/C0
      X=1./TAN(K*D1)/ZC
      YY11=CMPLX(0.,-X)
      X=-1./K/ZC/D1
      YY21=CMPLX(0.,X)
      X=K*R1
      CALL BESS(X,J01,Y01,J11,Y11)
      X=K*R2
      CALL BESS(X,J02,Y02,J12,Y12)
      Y=(J01*Y12-Y01*J12)/(J02*Y01-Y02*J01)
      Y=Y*2.*PI*R2/D1/SQRT(U0/E0)
      YY22=CMPLX(0.,-Y)
C THE FOLLOWING FORM THE SHUNT AND SERIES IMPEDANCES OF THE PI NETWORK
      Y1=YY11-YY21
      Z2=1./YY21
      Y3=YY22-YY21
C NOW USE ABCD MATRICES TO ANALYSE THE CIRCUIT
C A,B,C AND D ARE THE ABCD MATRIX OF THE EQUIVALENT CIRCUIT
      A=1.+Z2*Y3
      B=Z2
      C=Y1+Y3*(Y1*Z2+1.)
      D=Y1*Z2+1.
      S11=(A+B/50.-C*50.-D)/(A+B/50.+C*50.+D)
  ZIN=(A*50.+B)/(C*50.+D)/50.
C RHO IS THE VSWR
      RHO=(1.+ABS(S11))/(1.-ABS(S11))
```

```
C RL IS THE RETURN LOSS
      RL=20.*LOG10((RHO+1.)/(RHO-1.))
      WRITE(6,8)FG,RL,ZIN
8     FORMAT(2F10.2,2F10.3)
      F=F+FINC
      IF(F.LE.FU)GO TO 10
      WRITE(6,100)
100   FORMAT(' AGAIN?  ')
      READ(5,101)ANS
101   FORMAT(A1)
      IF(ANS.EQ.'Y'.OR.ANS.EQ.'y')GO TO 1000
      END
C ***********************************************************
      SUBROUTINE BESS(X,J0,Y0,J1,Y1)
C COMPUTES THE BESSEL FUNCTIONS J0,Y0,J1 AND Y1  FOR VARIABLE X
      REAL*4 J0,J1
      PI=3.14159265358979
      IF(X.GT.3.)GO TO 1
      J0=1.-2.2499997*(X/3.)**2+1.2656208*(X/3.)**4
      J0=J0-.3163866*(X/3.)**6+.0444479*(X/3.)**8
      J0=J0-.0039444*(X/3.)**10+.0002100*(X/3.)**12
      Y0=(2./PI)*LOG(X/2.)*J0+.36746691
      Y0=Y0+.60559366*(X/3.)**2-.74350384*(X/3.)**4
      Y0=Y0+.25300117*(X/3.)**6-.04261214*(X/3.)**8
      Y0=Y0+.00427916*(X/3.)**10-.00024846*(X/3.)**12
      J1=.5-.56249985*(X/3.)**2+.21093573*(X/3.)**4
      J1=J1-.03954289*(X/3.)**6+.00443319*(X/3.)**8
      J1=J1-.00031761*(X/3.)**10+.00001109*(X/3.)**12
      J1=J1*X
      Y1=(2./PI)*X*LOG(X/2.)*J1-.6366198
      Y1=Y1+.2212091*(X/3.)**2+2.1682709*(X/3.)**4
      Y1=Y1-1.3164827*(X/3.)**6+.3123951*(X/3.)**8
      Y1=Y1-.0400976*(X/3.)**10+.0027873*(X/3.)**12
      Y1=Y1/X
      RETURN
1     TH=X-.78539816-.04166397*(3./X)
      TH=TH-.00003954*(3./X)**2+.00262573*(3./X)**3
      TH=TH-.00054125*(3./X)**4-.00029333*(3./X)**5
      TH=TH+.00013558*(3./X)**6
      F0=.79788456-.00000077*(3./X)-.00552740*(3./X)**2
      F0=F0-.00009512*(3./X)**3+.00137237*(3./X)**4
      F0=F0-.00072805*(3./X)**5+.00014476*(3./X)**6
      J0=1./SQRT(X)*F0*COS(TH)
      Y0=1./SQRT(X)*F0*SIN(TH)
      TH=X-2.35619449+.12499612*(3./X)
      TH=TH+.00005650*(3./X)**2-.00637879*(3./X)**3
      TH=TH+.00074348*(3./X)**4+.00079824*(3./X)**5-.00029166*(3./X)**6
      F1=.79788456+.00000156*(3./X)+.01659667*(3./X)**2
      F1=F1+.00017105*(3./X)**3-.00249511*(3./X)**4
      F1=F1+.00113653*(3./X)**5-.00020033*(3./X)**6
      J1=1./SQRT(X)*F1*COS(TH)
      Y1=1./SQRT(X)*F1*SIN(TH)
      RETURN
   END
```

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